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Advanced Intermediate Heat Transport Loop Design Configurations for Hydrogen Production Using High Temperature Nuclear Reactors

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INTRODUCTION

The Department of Energy is investigating the use of high-temperature nuclear reactors to produce hydrogen using either thermochemical cycles or high-temperature electrolysis. Although the hydrogen production processes are in an early stage of development, coupling either of these processes to the high-temperature reactor requires both efficient heat transfer and adequate separation of the facilities to assure that off normal events in the production facility do not impact the nuclear power plant.

A number of possible configurations for an intermediate heat transport system that transfers heat between the reactor primary system and the hydrogen and/or electrical generation plant were identified. These configurations included both direct and indirect cycles for the production of electricity. Both helium and liquid salts were being considered as the working fluid in the intermediate heat transport loop. The HYSYS computer code was used along with other methods to perform thermal-hydraulic and cycle-efficiency evaluations of the different configurations and coolants. The thermal-hydraulic evaluations estimated the sizes of various components in the intermediate heat transport loop for the different configurations. The relative sizes of components will provide a relative indication of the capital cost associated with the various configurations.

DESIGN CONFIGURATIONS

A number of plant configurations were evaluated as part of this study. For convenience, the following nomenclature is used relative to the intermediate heat transport loop:

The configurations include direct and indirect electrical cycles with serial or parallel heat exchanger options. In the serial option, which is illustrated in Figure 1, the intermediate heat exchanger (IHX) is located between the reactor outlet and the power conversion unit (PCU). In the serial option, the IHX removes less than 10% of the reactor power and directs it towards the hydrogen production plant. With this configuration, the hydrogen production plant receives a higher temperature fluid than the PCU. This configuration is relatively simple and is especially suitable for the demonstration of hydrogen production. However, the overall efficiency of the electrical production process may be reduced because the PCU receives a lower temperature fluid. In the parallel heat exchanger option, which is illustrated in Figure 2, the hot fluid is split, with most going towards the PCU and the remainder going towards the hydrogen production plant. This configuration is more complicated, but results in a higher overall efficiency because both the electrical and hydrogen production plants see the maximum possible temperature. With the parallel option, a small compressor or blower is required to compensate for the pressure loss across the IHX and to allow the fluid streams to mix downstream of the recuperator. Due to the page limit, only two configurations are described with preliminary results.

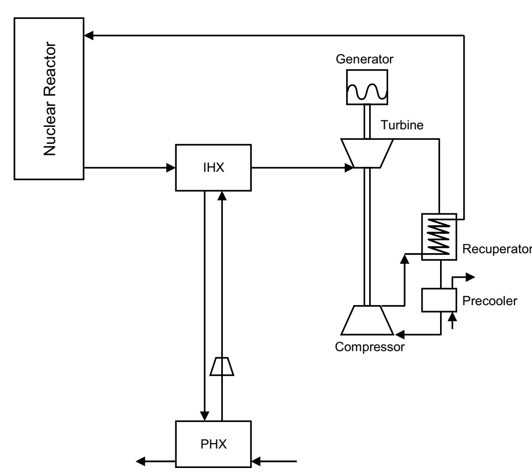

Figure 1. Configuration 1 (direct electrical cycle and serial IHX).

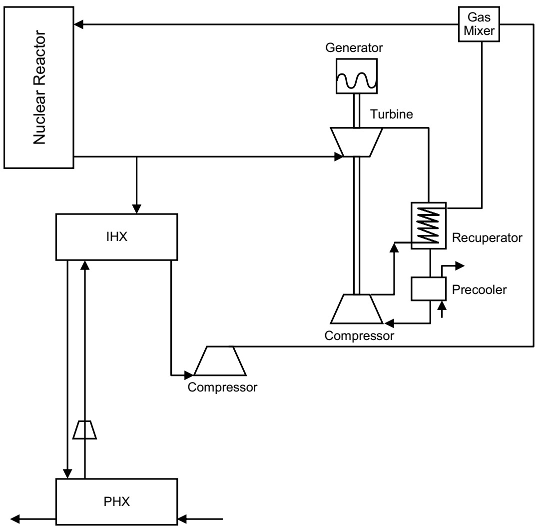

Figure 2. Configuration 2 (direct electrical cycle and a parallel IHX).

RESULTS

Evaluations were performed to determine various thermal-hydraulic parameters, such as the thermodynamic state, mass flow rate, etc., at various locations in the intermediate heat transport loop for the configurations illustrated in Figures 3 and 4. The nominal pressure in the intermediate heat transport loop was 2.0 MPa based on the material stress considerations. The other thermal-hydraulic parameters were primarily a consequence of the assumptions, requirements, and the need to obtain relatively large log-mean temperature differences across the heat exchangers to reduce their size.

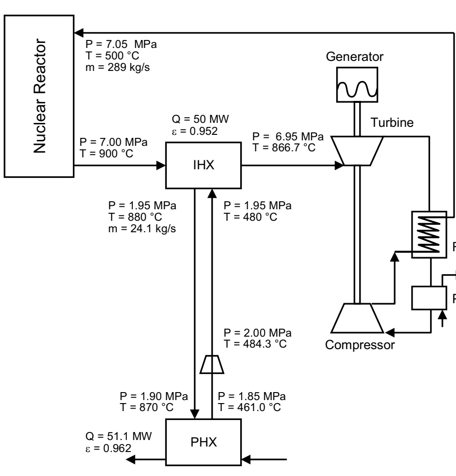

Figure 3. Thermal-hydraulic conditions for Configuration 1 with low-pressure helium.

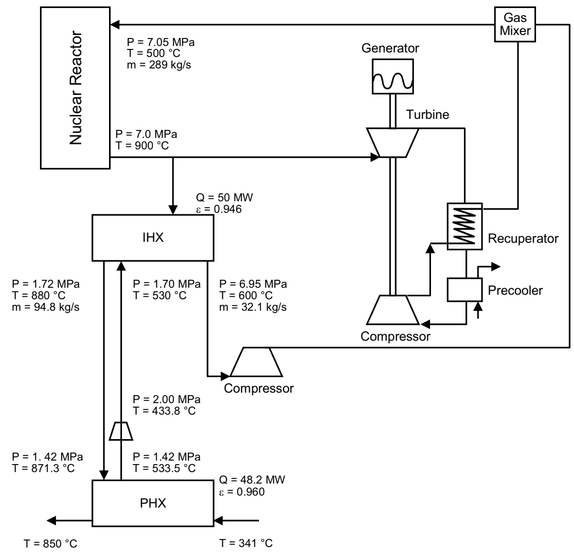

Figure 4. Thermal-hydraulic conditions for Configuration 2 with low-pressure helium.

CONCLUSIONS

Some of the conclusions from this phase of the study are:

- The use of an indirect cycle causes the overall efficiency of the plant to decrease by 1.1% compared to a direct cycle based on the temperature drop assumptions used for this analysis.

- The use of a parallel heat exchanger in the intermediate loop causes the overall efficiency to increase by 0.1 – 0.3% compared to use of a serial heat exchanger.

- The variations in overall efficiency were generally small between configurations.

ACKNOWLEDGMENT

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REFERENCES

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